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CENTRAL INTELLIGENCE AGENCY

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NEW DATA ON PHYSICAL AND TECHNICAL PARAMETERS OF FLASH TUBES

I.S. Marshak and L.I. Shchukin

The authors have summarized their paper as follows:

Investigations were conducted of extreme cases in the construction and feeding parameters of flash tubes with a limited discharge column (capillary tubes), and with an unlimited discharge (lamps with spherical bulbs) in a minimum inductance circuit.

Discharge characteristics in capillaries are similar to that in wide diameter tubes; the picture as a whole is shifted to the region of electric fields with a 5-10 fold magnification.

The specific resistance of plasma becomes almost constant (equalling ~ 0.02 ohm x cm.) at $E \gtrsim 120$ v/cm. The discharge extinction voltage increases approximately inversely proportional to the inner diameter of the tube.

The increase of the light efficiency stops at $E \cong 400$ v/cm (reaching very high values about 40 lumen/W). The dependence of the flash duration τ on constructive data and feeding parameters within wide change limits of both was determined. Within narrow limits of parameter modifications the following expression may be used:

$$\tau = AU_0^{-0.6} (C\ell)^p d^{-q}$$

Here A is the proportionality coefficient, U_0, the feeding condenser initial voltage, C, the condenser capacity, ℓ and d, the length and the inner diameter of the tube, p and q, the approximately constant coefficents, which by the wide modification of parameters change accordingly from 0.5 to 1 and from 0.5 to 2.

The influence of the discharge circuit inductivity on the luminous characteristics of tubular lamps is but insignificant. The acting temperatures of quartz and glass tubular lamps, which are on long duration stroboscopic duty (accordingly 750 and 250°C) are attained at mean wattages accordingly about 10 and 1.8 W per 1 cm of the tube length. The tubes perform for a few seconds (without compulsory cooling) at wattages which accordingly are equal to 40 and 4 w/cm.

The load factor (CU^4) max which determines load limits for glass tubes in single flash operation conditions does not depend on the d in the range changing from 0.5 to 11 mm and for quartz tubes in the range of 0.5 to 2 mm. The time necessary for the deionization of the gas gap in capillary quartz tubes, dissipating ~ 2 w/cm increases from 80 to 270 μsec at a growth of the initial electric field from 140 to 280 v/cm. In case of a high wattage the deionization period drops from 500 to 300 μsec. Accordingly, critical flash frequencies of such tubes without any additional commutation element in the discharge circuit at low wattages is equal to 12 kilocycles/sec and at higher wattages about 3 kc/sec.

In order to investigate extreme discharge performances in tubes with spherical bulbs, various kinds of ceramic (discus, cylindric and pot), quartz (cylindric and spheric) and film (cylindric) low induction condensers in conjunction with constructive elements of the tubes (discus and coaxial lead-ins, connections and electrodes) were tested.

As a result data of minimum possible inductive discharge circuits and their elements were obtained. Investigations were conducted of discharge column expansion velocities and of discharge characteristics at various feeding parameters. Constructive data and feeding parameters for the tubes with a flash duration of 0.1 μ sec, a flash frequency of 3 kc/sec and a wattage of 1 kW were established.

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NEW DATA ON PHYSICAL AND TECHNICAL PARAMETERS OF FLASH TUBES

I.S. Marshak and L.I. Shchoukin

The authors have summarized their paper as follows:

~~Summary~~

Investigations were conducted of extreme cases in the construction and feeding parameters of flash tubes with a limited discharge column (capillary tubes), and with an unlimited discharge (lamps with spherical bulbs) in a minimum inductance circuit.

Discharge characteristics in capillaries are similar to that in wide diameter tubes; the picture as a whole is shifted to the region of electric fields with a 5 - 10 fold magnification.

The specific resistance of plasma becomes almost constant (equalling $\sim$ 0.02 ohm x cm.) at E $\gtrsim$ 120 v/cm. The discharge extinction voltage increases approximately inversely proportional to the inner diameter of the tube.

The increase of the light efficiency stops at E $\cong$ 400 v/cm (reaching very high values about 40 lumen/W). The dependence of the flash duration τ on constructive data and feeding parameters within wide change limits of both was determined. Within narrow limits of parameter modifications the following expression may be used:

$$\tau = AU_0^{-0.6} (C\ell)^p d^{-q}$$

Here A is the proportionality coefficient, U_0, the feeding condenser initial voltage, C, the condenser capacity, ℓ and d, the length and the inner diameter of the tube,

p and q, the approximately constant coefficients, which by the wide modification of parameters change accordingly from 0.5 to 1 and from 0.5 to 2.

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The load factor (CU^4) max which determines load limits for glass tubes in single flash operation conditions does not depend on the d in the range changing from 0.5 to 11 mm and for quartz tubes in the range of 0.5 to 2 mm. The time necessary for the deionization of the gas gap in capillary quartz tubes, dissipating $\sim$ 2 w/cm increases from 80 to 270 μsec at a growth of the initial electric field from 140 to 280 v/cm. In case of a high wattage the deionization period drops from 500 to 300 μsec. Accordingly, critical flash frequencies of such tubes without any additional commutation element in the discharge circuit at low wattages is equal to 12 kilocycles/sec and at higher wattages about 3 kc/sec.

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As a result data of minimum possible inductive discharge circuits and their elements were obtained. Investigations were conducted of discharge column expansion velocities and of discharge characteristics at various feeding parameters. Constructive data and feeding parameters for the tubes with a flash duration of 0.1 μsec, a flash frequency of 3 kc/sec and a wattage of 1 kW were established.

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In addition to reports on physical and technical flash-tube characteristics published earlier /1 - 9/, in this series of experiments extreme cases of flash-tube constructions and their feeding parameters were studied.

Tubes with a very limited discharge channel (capillary tubes which are of special interest for Töppler photography) and with an unlimited discharge column (lamps with spherical bulbs and short spark gaps producing flashes with a maximum brilliancy, a minimum duration and an extremely small luminous volume) were investigated. In the latter case special attention was paid to the reaching of a maximum speed in the delivery of energy into the discharge column by an utmost inductance reduction in the discharge circuit.

The study of discharges in capillary tubes was practiced on quartz and glass lamps with an inner diameter of the tube equal to d= 0.2 - 1.1 mm and its length (not taking into account the widened parts at the electrodes) ℓ=10 -100mm. The tubes were filled with xenon, crypton and argon to a pressure of P = 50 - 920 mm of mercury. The feeding condensers were of C = 0.05 microfarads up to a few dozens of microfarads, charged to a voltage U from a few hundred volts to a few kV. When the tubes were used as strobotrons a current interruption in the condenser charging circuit, necessary for gas deionization, was secured in order to prevent the transition of the discharge to a stationary operating condition.

In table 1 feeding parameters are shown which are necessary for the filling of various diameter capillary tubes with a discharge column (xenon, p ≈ 600 mm of mercury, ℓ = 70 mm). These data were obtained by photographing singular discharges in capillary tubes. With equal flash energies, discharges with greater voltages and lesser capacities execute the filling of capillary tubes less satisfactory than discharges with inversion parameters.

Table 1 data comply with oscillographic investigations, which show a coincidence of positive slope branches in the voltage-current characteristics for the discharges, filling the capillaries /4/.

Table 1

d	C	U	$CU^2/2$
mm	μF	kV	j
1	0.5	1.5	0.56
0.5	0.1	1.5	0.11
0.3	0.025	0.8	0.008

In figure 1 diagrams are given of the plasma discharge specific resistance ϱ depending on the electric field strength E for capillary tubes and for wide tubular lamps of different diameters /4/. Figure 1 shows that the electric characteristics of the discharge in capillary tubes are similar to those which were obtained for tubular lamps, with the exception that the specific resistance begins to rise noticeably at electric field strengths which are 3 or 4 times greater. For practical estimates an approximate value ρ = 0.02 ohm·cm at field strengths $>$ 100 v/cm may be used. At E $>$ 100 v/cm ρ for xenon is 10-20 per cent greater than for argon. The decrease in gas pressure from 600 to 100 mm of mercury lowers ρ by 30 - 50 per cent.

The discharge extinction voltage, as expected /2/, increases speedily with the fall in d and the rise in P and ℓ (figure 2). Its ignition voltage depends but slightly on the diameter of capillary tubes, on the form and position of the exterior igniting electrode and is directly proportional to the length of the capillary tube, to the square root of pressure and is inversely proportional to the ignition pulse value (figure 3). The spontaneous breakdown voltage, which greatly scatters (especially in case the igniting electrode is not attached to the tube), exceeds the controlled ignition voltage by 5 - 15 times (a possible breakdown) and + 10 - 30 (a sure breakdown). Without the igniting electrode it becomes from 1.5 to 2 times greater.

The product of the candle-power amplitude J_a by the flash duration τ, measured at a 35 per cent amplitude level, for capillary tubes and for wide tubular lamps is equal to the candle seconds integral $\int J\,dt$ divided by a coefficient K = 0.86 $\pm$0.02, constant for all tubes and feeding parameters. The candle-power amplitude and flash duration τ are roughly proportional to the atomic number of the inert gas (see for instance table 2, which shows tube characteristics with d = 0.5 mm, ℓ = 70 mm, p = 600 mm of mercury, C = 0.25 μF, U = 1.2 kV).

Table 2

Gas	τ	Ia	$\int J\,dt$
	μsec	cd	cd.sec
Xenon	21.4 ±1.1	7900±280	0.15
Crypton	19.4 ±1.8	5100±280	0.082
Argon	12.6 ±0.4	2200±260	0.024

Ia reaches its maximum at a pressure of 100 mm of mercury, then it somewhat decreases with the increase of p, and at $\gtrsim$ 500 mm of mercury depends no more on p (figure 4). The flash duration increases with p up to 500 mm of mercury and then also attains constancy. $\int J\,dt$ gradually increases with p up to 300 mm of mercury, and does not depend on it at a greater p. With the increase of the capillary tube diameter, the candle power amplitude increases linearily with d, and $\int J\,dt$ increases speedily up to d = 0.5 mm and then goes up slower (figure 5).

The length of the capillary influences the light output in tubes shorter than 70 mm. The total electrode voltage drops

(including drops in the expansions close to the electrodes), determined by comparing the light output of various ℓ /8/, is equal to 150 V, roughly 3 times exceeding a similar value for wide tubular lamps.

With a longitudinal electric field strength $<$ 250 v/cm the light output η speedily increases with the increase in voltage, but at E $\gtrsim$ 400 v/cm it reaches the maximum value of $3.2 \frac{cd.sec}{j}$ (figure 6). An increase in the feeding condenser capacity leads to an increase in the light output up to C $\cong$ 1 μF (figure 7). The capillary tube light output values, obtained at great electric field strengths, exceed the light output of lamps with spherical bulbs and prove that capillary tubes may be widely used in high speed photography.

The inductance of the discharge circuit, in case it does not exceed 100 microhenries, practically does not influence the light characteristics of tubes, but if it increases up to 2500 μH the flash duration is doubled, the light output decreases 30 per cent and accordingly the candle power amplitude decreases 3 times.

Ample experimental material concerning the dependence of capillary tube and wide tubular lamp flash durations (at a 35 per cent level of the intensity maximum) on d, C, ℓ and E allows to draw a nomographic chart in order to determine τ for different conditions which is shown in figure 8. It may be observed, that within the narrow limits of parameter variations it is possible to consider the curvilinear diagram as a straight one and thus use a formula similar to the one already mentioned by other authors /10/:

$$\tau = A\, U_0^{-0.6} (\varrho \ell)^p d^{-q} \qquad (1)$$

Here A is the proportionality coefficient, U_0 - the initial voltage of the feeding condenser, p and q - the approximately constant coefficients (at $\tau \gtrsim 50$ μsec - they are roughly equal to 0.5; at $\tau \gtrsim 500$ μsec - $p = 1$, $q \approx 2$, which agrees with the proportionality between τ and the time constant RC of the discharge circuit, where R is the tube resistance computed by formula $R = \frac{\varrho \ell}{\pi \frac{d^2}{4}}$).

In figure 9 spectral characteristics of capillary tubes filled with various gases are shown. These characteristics were obtained by M.I. Epstein, who operated with a wide monochromator outlet slit and after plotting the spectrum in blocks /9/ used envelope plotting. These characteristics differ but little from the characteristics of wide tubular lamps. A modification in gas pressure (from 100 to 600 mm) and in the lamp feeding conditions (C from 0.25 to 0.5 μF, U from 0.8 to 1.2 kV) practically does not influence spectral characteristics (not taking into account a 30 per cent intensity increase in the 900 - 1200 mμ region, when the operating voltage decreases from 1.2 to 0.8 kV).

In stroboscopic operations the wattage permissible for quartz and glass capillary tubes is respectively 10 and 1.7 W per cm of the tube length. For short-time operations the wattage may be increased 2 - 2.5 times.

In single-flash operations the maximum loads do not differ from respective loads of wide tubular lamps with equal C.ℓ. In this regime the dependence of the load-limit on capacity and voltage is characterized by a constancy of the load factor (CU^4)max /2, 5, 6/. Thus, the regularities already revealed may be applied to inner tube diameters ranging from 0.5 to 15 mm.

The time-lags between the igniting pulse and the beginning of the flash are of a stable nature (the scattering does not exceed 0.1 μsec), and, with a modification of the operating voltage U_0 within the limits of 0.8 -1.2 kV (ℓ= 70 mm), and the voltage U_I on the primary of the igniting transformer of 0.8 to 1.35 kV, are within a 4 to 18 μsec limit, approximately linearily decreasing with the increase of U_0 in the above-mentioned range.

In figure 10 diagrams of the gas deionization time of capillary tubes are given. The deionization time was determined as a value reciprocal to the maximum flash frequency at a given feeding voltage and at the condenser charging time equal to the duration of its discharge through the tube (the rest of the time the voltage on the tube was equal to the discharge extinction voltage). Owing to the fact that at great wattages dissipated in the tube and its low feeding voltages the discharge duration is comparable with the deionization time, the diagram shows dotted line branches which correspond to the erroneous increase in the deionization time when operating voltages are decreasing. The true deionization time (solid lines) substantially decreases with the decrease in the dissipated wattage at high feeding voltages. From figure 10 it follows, that at 15 watts and an operation voltage of 1 kV, these tubes may be used without any additional commutating device in the discharge circuit at a flash frequency up to 12 kilocycles per second (at a "momentary" charging of a condenser prior to the flash). An increase in the average wattage up to 70 watts corresponds to the decrease in the maximum flash frequency up to 4 kilocycles. At this wattage it is advisable to select the higher operational voltage (about 1.8 kV) in order to reduce the discharge duration and to provide a greater interval which is necessary for the gas deionization.

The study of discharges with a short unlimited column, was conducted on lamps which were similar to commercial tubes ИСШ 100 and ИСШ 500, and also on tubes with a minimum inductivity of the current lead-ins which were constructed in the form of two parallel covar discs sealed into the glass (figure 11). The tubes were filled with xenon and argon (pure and with an admixture of hydrogen) at a pressure of a few atmospheres. Various kinds of low-induction condensers (ceramic-disc, cylindric and pot; quartz - cylindric and spheric; film-cylindric) were used for tube feeding; these condensers were coupled with the tubes by low-induction constructive elements.

The oscillographic studies of various discharge circuits show, that the minimum inductivity L attained is equal to $5 - 6 \cdot 10^{-9}$ Hy (for cylindrical film and ceramic disc condensers). The inductivity of certain circuit elements, including the discharge column, may be computed by the existing formulas (for instance, a column 5 mm long and 0.3 mm in diameter has an inductivity of $3.3 \cdot 10^{-9}$ Hy). Parallel coupling of cylindric condensers by coaxial contact cylinders and the connection of a tube with a condenser by a low-inductivity cable of a rectangular cross-section increases the inductivity of the circuit by $10-20 \cdot 10^{-9}$ Hy.

The study of the discharge column expansion in the range of low L conducted by a Leningrad Institute of Cinema Engineers' high speed raster camera /11/ has shown that the expansion picture agrees with the data of other authors obtained at greater L. The initial speed V_0 of the channel radius growing does not depend on C and modifies with U and L in accord with the formula:

$$V_0 = A \sqrt{U} \quad \lg \frac{9 \cdot 10^4}{L^{3/2}} \qquad (2)$$

(U in kV, L in 10^{-9} Hy, V_0 in mm/μsec, A for Xe + 20% H_2 is equal to 0.37, for Kr + 20% H_2 - 0.4, for Ar +20% H_2 - 0.45). Besides V_0 the expansion process is characterized

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by the value $\left(\frac{t}{d^2}\right)_{min}$ which may be attached to the tempo of the channel expansion as a whole (see figure 12 which shows a curve of $\frac{t}{d^2}$ versus time). Empirical equations connecting $\left(\frac{t}{d^2}\right)$ min. and respective values t_{cr}, d_{cr} as well as d_{max} with discharge parameters take the following form (Xe + 20% H_2, 3 atm., ℓ = 5 mm):

$$\left(\frac{t}{d^2}\right)_{min} = \frac{30}{\sqrt{CU^2/2}} + 0.12(L-120) \quad (3)$$

$$t_{cr} = 2.45 + 0.007\,CU(L-120) \quad (4)$$

$$d_{cr} = 0.24\sqrt{CU} \quad (5); \qquad d_{max} = 1.22\,d_{cr} \quad (5a)$$

An oscillographic study of the electric pulse at various discharge parameters has shown that the effective resistance of the column (measured by the damping of oscillations) modifies with the column diameter d and the electric field strength just as if the column is a homogeneous conducting cylinder with a specific resistance ρ, the same as it was found for the discharge in the tubular lamps (with an equal electric field strength). On the basis of data concerning the dependence of ρ on E (for great E the formula $\rho = \frac{0.09}{\sqrt{E}}$ ohm . cm may be accepted), and taking as an effective value of E the temporary move: $E = E_0 e^{-\frac{R}{2L} \cdot t}$ the dependence of the column resistance on time may be obtained:

$$R = \frac{0.09\,\ell}{\frac{\pi}{4}\sqrt{E_0}} \cdot \frac{e^{\frac{Rt}{4L}}}{t} \cdot \left(\frac{t}{d^2}\right). \quad (6)$$

Taking into account that in the range of t values from $\frac{L}{2R}$ to $\frac{4L}{R}$ (which corresponds to the pulse duration on the level of $\frac{1}{e^2}$) the value $\frac{e^{-\frac{Rt}{4L}}}{t}$ changes insignificantly, the dependencies R_{min} and $\left(\frac{t}{d^2}\right)_{min}$ on parameters should be similar. Thus, on the basis of formulas (2) and (5) we may compute for various discharge parameters the value $\frac{CR^2_{min}}{4L}$, which determines to what extent the discharge is close to the aperiodic condition ($\frac{CR^2_{min}}{4L} \geqslant 1$). Respective diagrams are shown in figure 13. These curves, in agreement with direct experimental observations show, that an unlimited discharge without a ballast resistance may be aperiodical at a flash energy of up to 0.5j, with an inductivity up to $6 \cdot 10^{-9}$ Hy and a feeding voltage up to 2.5 kV. Quickest of all the value $\frac{CR^2_{min}}{4L}$ decreases with the increase in voltage (at U = 5 kV aperiodic condition is granted by L lower than $1 \cdot 10^{-9}$ Hy). The value $\frac{CR^2_{min}}{4L}$ exceeds 0.4 (hereat in the half of the period the discharge wattage decreases tenfold) at 2.5 kV and $20 \cdot 10^{-9}$ Hy or 5 kV and $3 \cdot 10^{-9}$ Hy.

The aperiodic discharge may be obtained using a low-inductivity ballast resistance R in series with a tube on condition that $\sqrt{\frac{L}{C}} < R < 1.4\sqrt{\frac{L}{C}}$ (for 0.01 to 5 j flash energies).

Electric and light pulses with respective durations 0.05 μsec and 0.1 μsec (on a 35 per cent level) may be obtained without any special ballast in Ar + 20% H_2 at $p \cong 3$ atm, $\ell \cong 5$ mm, $L \cong 10 \cdot 10^{-9}$ Hy, $U \cong 3$ kV and $C \cong 3000 \mu\mu F$, and with a ballast and the same other conditions at

$C \cong 0.01$ μF, $U \cong 8$ kV, $R \cong 1.2$ ohm. In the second case the luminous intensity amplitude is approximately 40 per cent more than in the first instance. The flash duration, measured by the brightness curve at a 35 per cent level of its amplitude value, in the parameter range studied, is about half of the flash duration, measured by the candle power curve.

The duration of light pulse τ in the process of a discharge in a lamp with a spherical bulb without any ballast linearily increases with the voltage square on the condenser, with the square root of its capacity and the root in the sixth degree of the discharge circuit inductivity (figures 14 - 16). It decreases with the lengthening of the spark gap (figure 17), and also with the increase of the gas pressure and the diminution of its atomic number.

With a ballast the influence on τ of all the factors mentioned, with the exception of the gas nature gets weaker; the gas nature shows its influence just the same as without any ballast.

The light output of a discharge in such lamps but weakly modifies with a change in the voltage and capacity of the feeding condenser (figure 18). The candle ~~power~~ amplitude per energy unit, with an increase of $\frac{CU^2}{2}$ from 0.05 to 0.8 j decreases from 2.5×10^6 (xenon) + 1.2×10^6 (argon plus 20% H_2) cd/j to respectively 0.8 + 0.6 x x 10^6 $\frac{cd.}{j}$ (p = 3 atm, ℓ = 6 mm, L = $120 \cdot 10^{-9}$ Hy, C = 0.005 – 0.04 μF. The decrease of L from 100 to $10 \cdot 10^{-9}$ Hy leads to an increase in the candle power amplitude by 20%. The diminution of the inert gas atomic number or an addition of 20% hydrogen leads to a decrease in the candle power amplitude by 10 – 20%.

The maximum frequency f_{max} of the flash repetition is connected with the kind of the feeding circuit, with the feeding voltage, with the wattage dissipation P and with the constructive data of the tube (the gas filling, the electrodes).

Examples of the f_{max} dependence on P for three circuits which were used for lamps with a 65 mm bulb diameter, a gas pressure of 3.2 atm and a 5.5 mm gap between the electrodes are shown in figures 19 – 21. In figure 22 are shown the deionization time curves which were received from data on a maximum flash frequency.

The data obtained show that there is a possibility of getting 0.3 μsec flashes at a frequency of 5 kilocycles with an average wattage of 1 kW, without any commutating device in the discharge circuit.

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Legends to Figures

1. The dependence of the plasma specific resistance on the electric field strength for three diameters of capillary tubes (full lines, xenon, p = 600 mm of mercury, l = 70 mm, C up to 0.5 μF, U up to 1.5 kV). The dashes show the region of the somewhat enlarged ρ - values for d = 1 mm, because the capillary tube is not fully filled. The dotted line is the same dependence for wide tubular lamps /4/.
2. An example of discharge extinction voltage dependencies on diameter, gas pressure and tube length (xenon).
3. An example of discharge igniting voltage dependencies on tube length, gas pressure and voltage U_I on the primary winding of the igniting pulse transformer (xenon, d = 0.5 mm).
4. An example of candle power amplitude, intensity-time integral and flash duration dependencies on xenon pressure (d = 0.5 mm, l = 70 mm, C = 0.25 μF, U = 1.2 kV).
5. Candle power amplitude and intensity-time integral dependencies on the tube diameter (xenon, P = 600 mm of mercury, l = 70 mm, C = 0.25 μF, U = 1.2 kV).
6. Candle power amplitude, intensity-time integral and light output dependencies on E (xenon, P = 600 mm of mercury, d = 0.5 mm, l = 70 mm, C = 0.25 μ F).

7. Light output dependency on C (U = 1.2 kV; the same other parameters).
8. On the left is the group of dependencies of τ on Cl with different d and the initial electric field strength E_0 = 100 v/cm. On the right is the displacement of the ordinate scale with a change in the initial electric field strength.
9. Spectral characteristics of capillary tubes filled with xenon, crypton and argon (P = 600 mm of mercury, d = 0.5 mm, ℓ = 70 mm, C = 0.25 μF, U = 1.2 kV).
10. Deionization time curves for capillary tubes (quartz, d = 0.5 mm, ℓ = 70 mm, xenon, P = 600 mm of mercury) with wattage dissipation from 12.5 to 200 W. The dotted line branches are the regions of τ erroneously increased by the discharge duration time.
11. Construction of low-inductivity tubes and discharge circuits with a disc ceramic condenser. 1 - tube, 2 - condenser, 3 - covar disc, 4 - ballast resistance.
12. Dependence curve of $\frac{t}{d^2}$ on t(Xe + 20% H_2, P = 3 atm, U = 7 kV, C = 0.1 μF, L_2 = 120 $\cdot 10^{-9}$ Hy, ℓ = 6 mm).
13. Dependence of value $\frac{CR^2_{min}}{4L}$ on flash energy at various U_0 and L(Xe + 20% H_2, P = 3 atm, ℓ = 6 mm).
14. An example of τ dependence on voltage square (C = 0.005 μF, ℓ = 6 mm, L = 10 $\cdot 10^{-9}$ Hy).
15. An example of τ dependence on C (ℓ = 6 mm, P = 2.5 atm).

16. An example of τ dependence on L (ℓ = 6 mm, P = 2.5 atm).
17. An example of τ dependence on ℓ (xenon, p - 3 atm, C - 0.01 μF, L = 200 $\cdot 10^{-9}$ Hy).
18. Dependence of the light output on average wattage P dissipated in the tube (p = 3 atm, ℓ = 6 mm, L = 120 $\cdot 10^{-9}$ Hy) at various flash frequencies f .
19. Dependence of f_{max} on P at different charging current pauses θ (as part of the flashing period $T = \frac{1}{f}$) in a circuit controlled by a thyratron (Xe + 20% H_2).
20. Dependence of f_{max} on P in a circuit with a "tilting arm" /12/.
21. Dependence of f_{max} on P in a circuit ~~xxxxx~~ controlled by a vacuum triode (U = 6.5 kV).
22. Dependence of the deionization time on operation voltage at different wattages.

I. Marshak
L. Shchukin

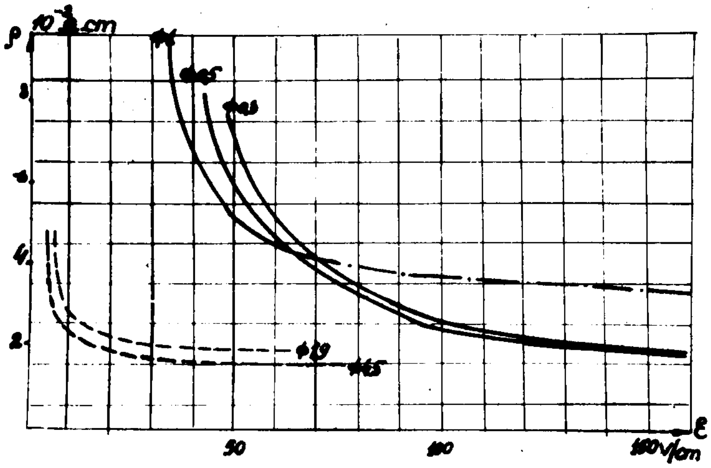


fig. 1

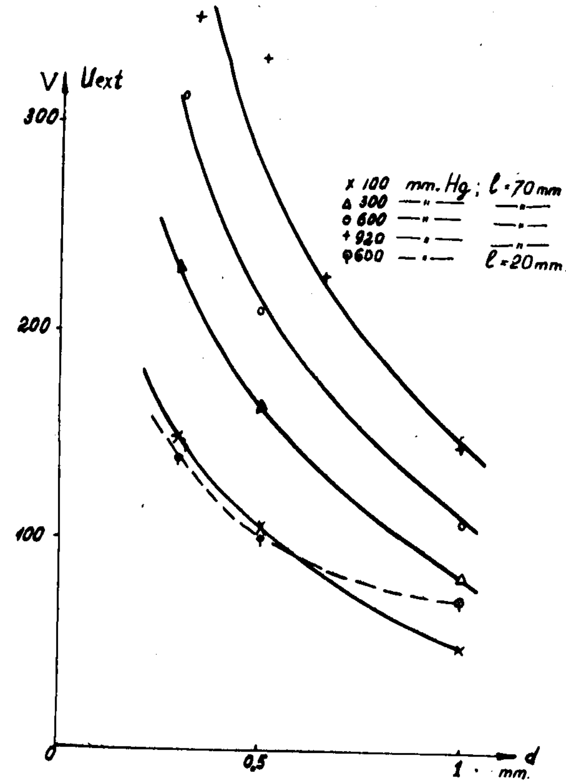
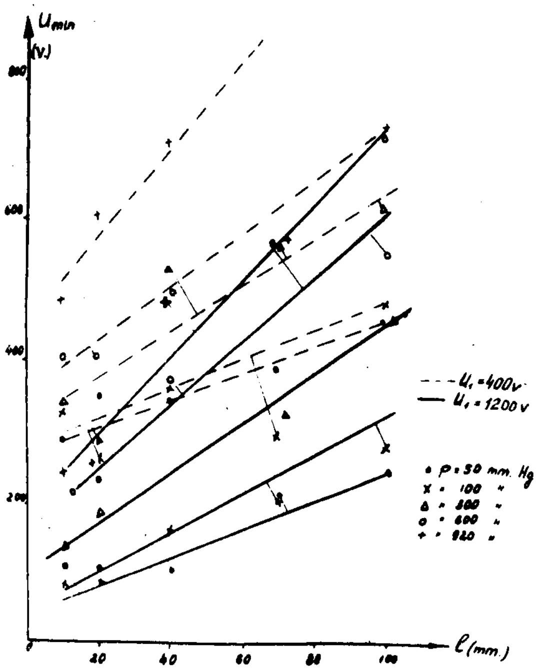


fig. 2



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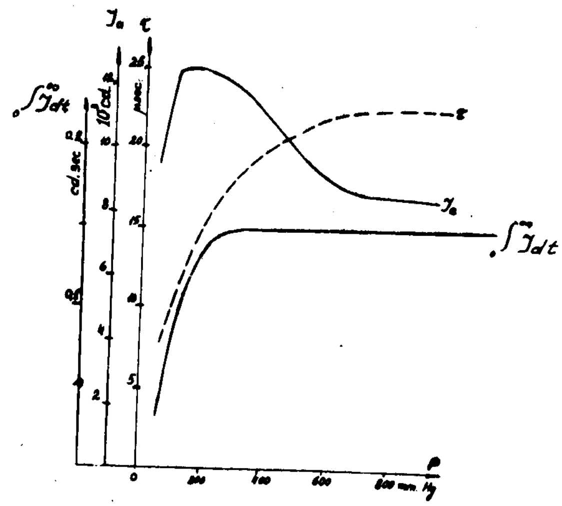

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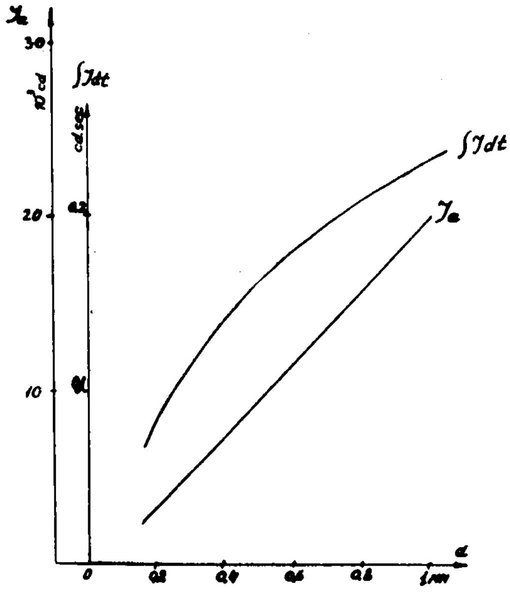

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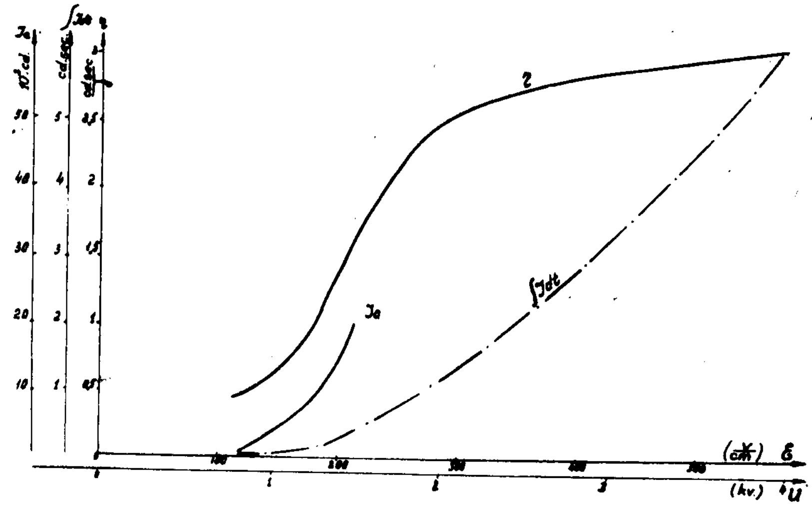

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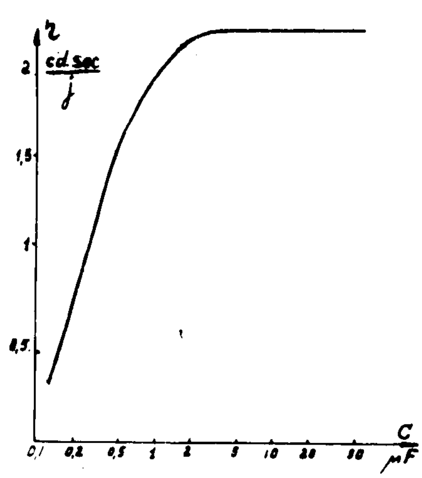

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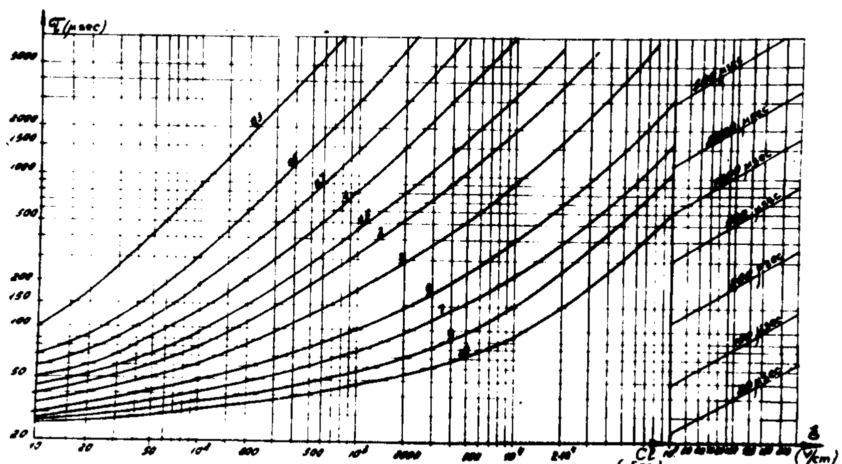
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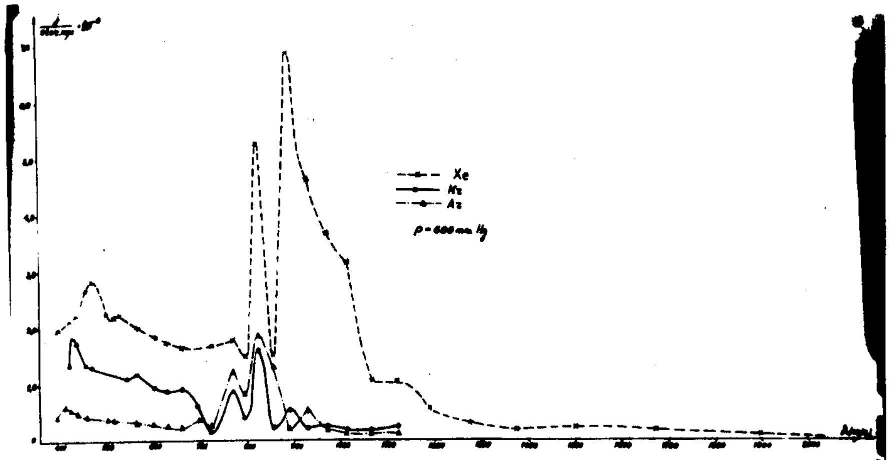


fig 9

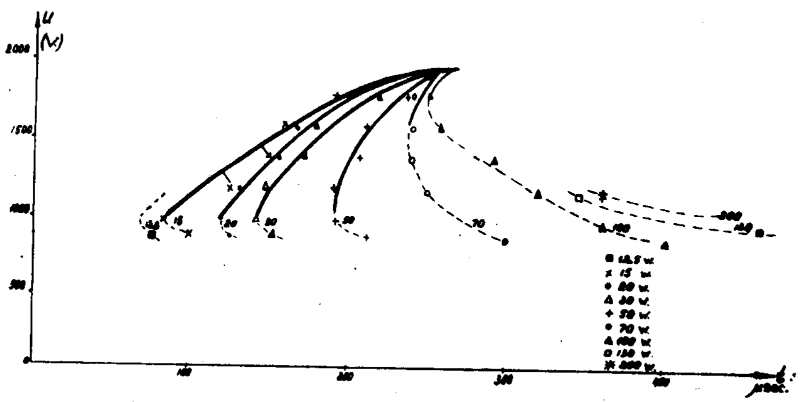


fig. 10

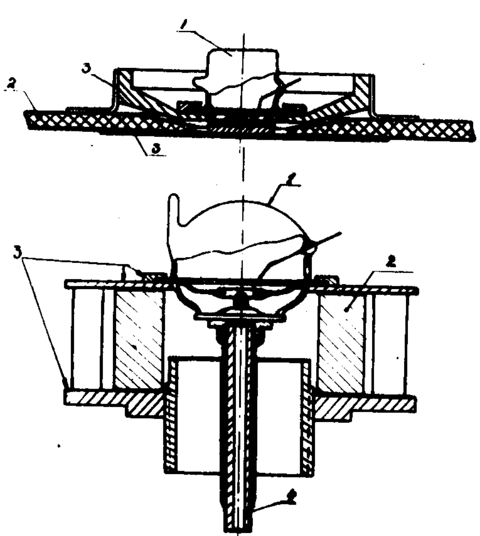


fig 11

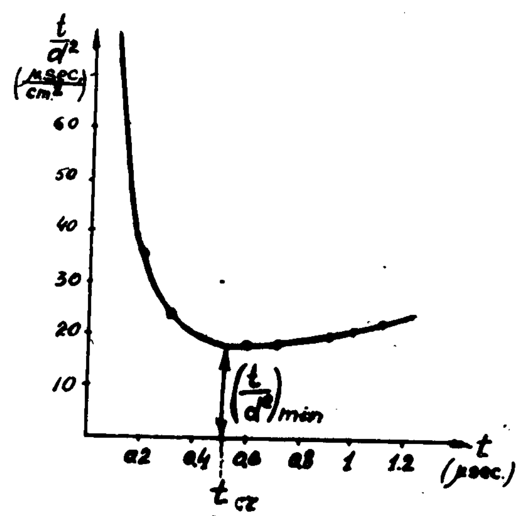


fig. 12

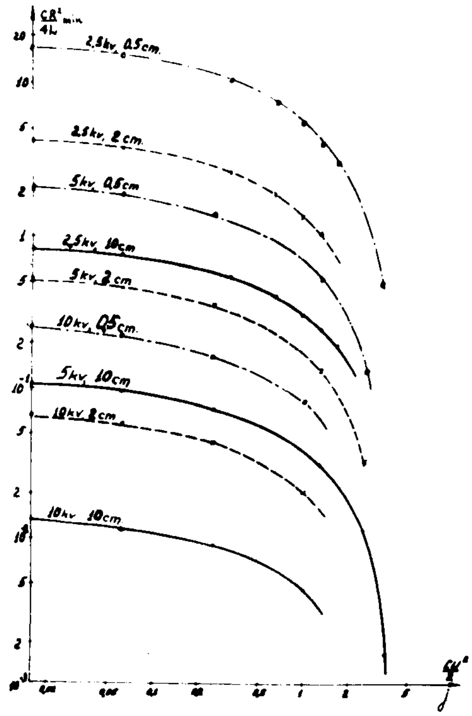


fig. 13

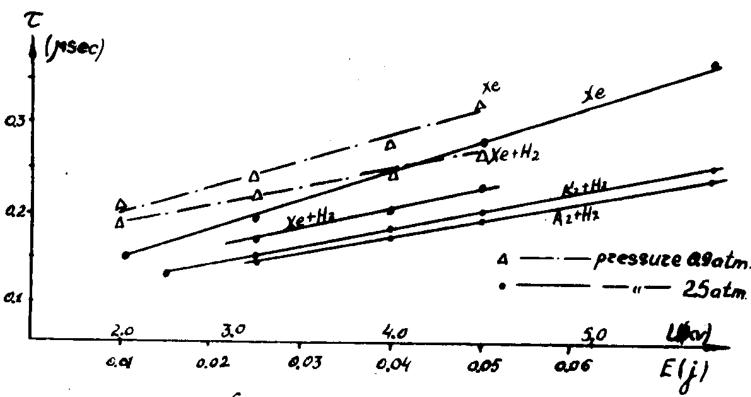


fig. 14

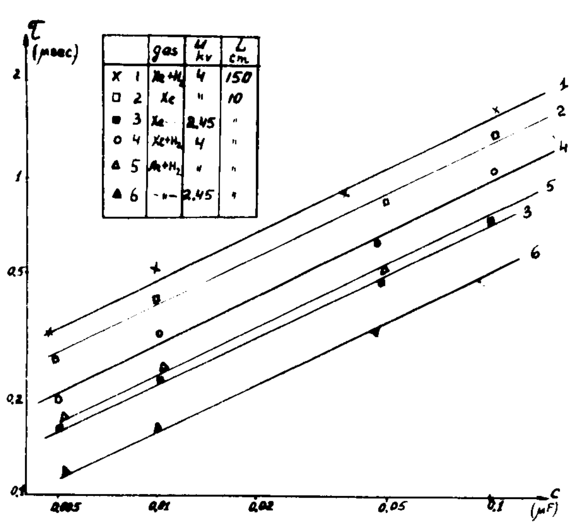


fig. 15

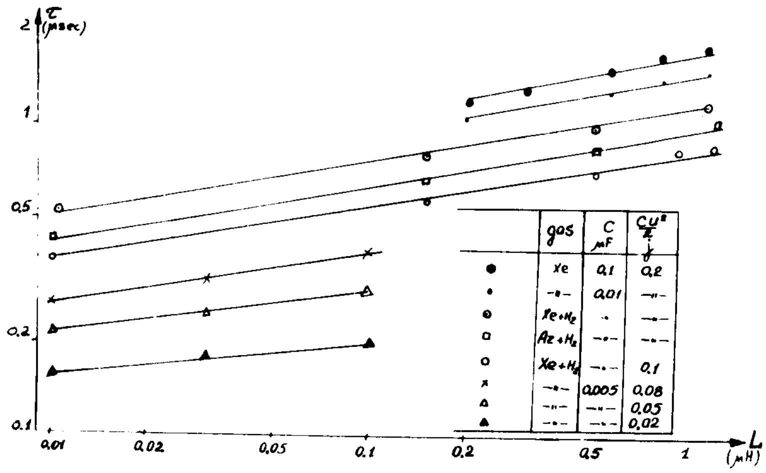


fig. 16

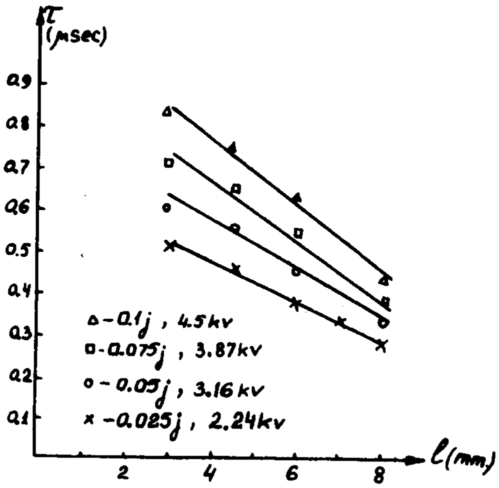


fig. 17

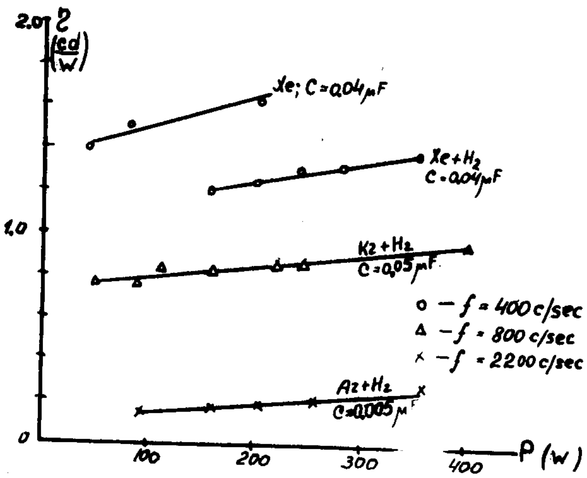


fig. 18

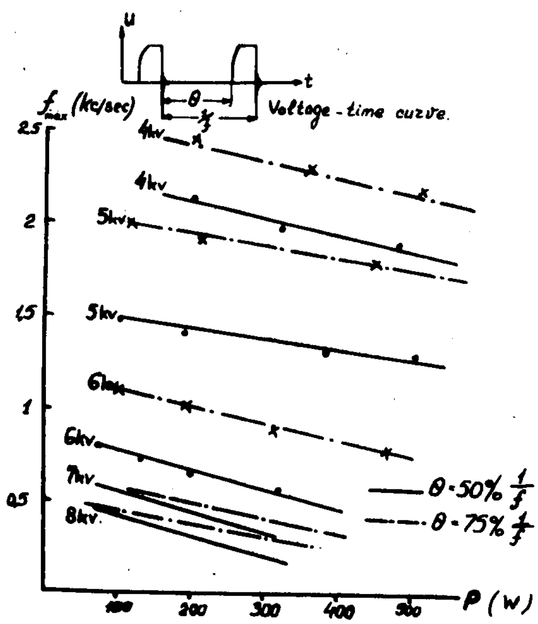


fig. 19

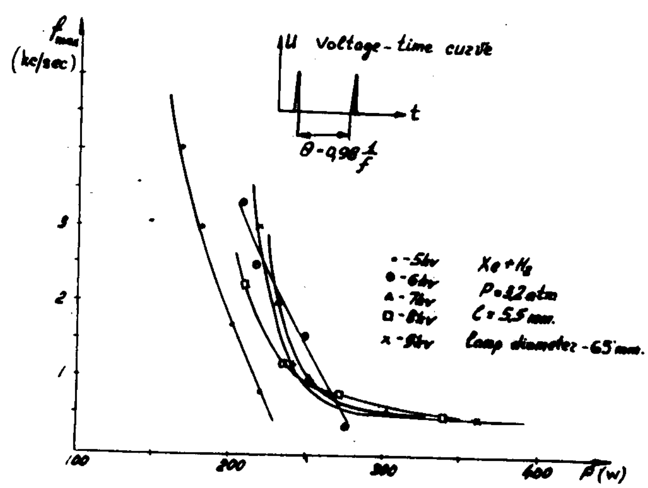
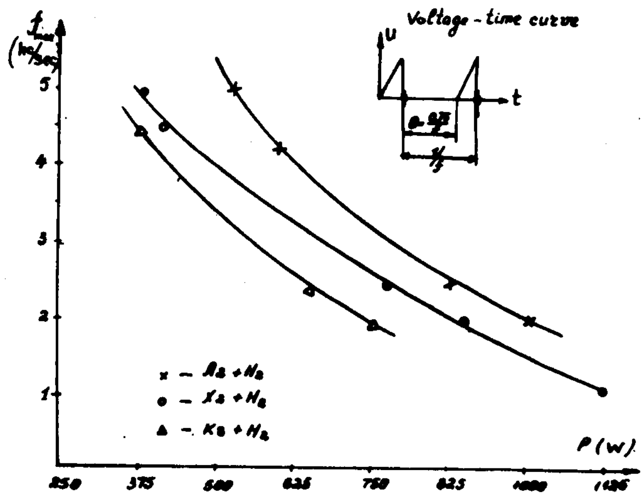
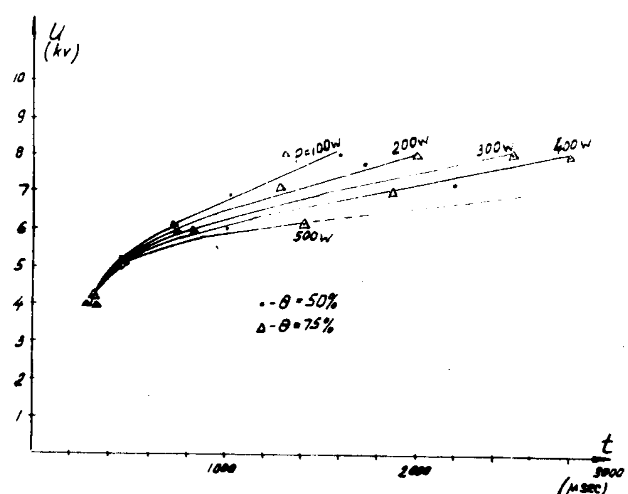


fig. 20



Voltage - time curve
u
t
P (w)
x – Ar + H2
• – Xe + H2
▲ – Kr + H2
250
375
500
625
750
825
1000
1125

fig.21



U
(kv)
p=100w
200w
300w
400w
500w
• - θ = 50%
Δ - θ = 75%
t
1000
2000
3000
(μsec)

fig. 22